

Table of Contents

1. Characteristics of the Sun	1
1.1 Distance	2
1.2 Mass	3
1.3 Radius	4
1.4 Luminosity	5
1.5 Spectral Energy Distribution	8
1.5.1 Energy Flux and Intensity	8
1.5.2 The Visible	9
1.5.3 The Infrared	10
1.5.4 The Radio Spectrum	11
1.5.5 The Ultraviolet	12
1.5.6 Extreme Ultraviolet and X-rays	13
1.5.7 Color Indices	14
1.6 Bibliographical Notes	15
2. Internal Structure	17
2.1 Construction of a Model	17
2.1.1 The Evolutionary Sequence	17
2.1.2 The Standard Model	19
2.2 Age and Pre-Main-Sequence Evolution	20
2.3 Model Ingredients	24
2.3.1 Conservation Laws	24
2.3.2 Energy Transport	25
2.3.3 Element Diffusion in the Interior	27
2.3.4 The Equation of State	30
2.3.5 The Entropy	36
2.3.6 Nuclear Energy Sources	38
2.3.7 The Opacity	47
2.3.8 Boundary Conditions and Method of Solution	51
2.4 Results for a Standard Solar Model	54
2.4.1 General Evolution	54
2.4.2 Neutrinos	57
2.5 Non-Standard Models	61
2.5.1 The Low- Z Model	62

2.5.2	Rapidly Rotating Core	62
2.5.3	Internal Magnetic Field	63
2.5.4	The Internally Mixed Model	63
2.6	Bibliographical Notes	64
3.	Tools for Solar Observation	67
3.1	Limitations	67
3.1.1	General Difficulties	67
3.1.2	Seeing: Description and Definitions	69
3.1.3	Seeing: How to Live with It	73
3.1.4	Adaptive Optics	81
3.1.5	Image Restoration	83
3.2	High-Resolution Telescopes	85
3.2.1	Image Scale	85
3.2.2	Mirrors for Fixed Telescopes	86
3.2.3	Telescopes with Long Primary Focus	89
3.2.4	Telescopes with Short Primary Focus	94
3.3	Spectrographs and Spectrometers	99
3.3.1	The Grating Spectrograph	99
3.3.2	The Fourier Transform Spectrometer	101
3.3.3	The Measurement of Line Shifts	103
3.4	Filters and Monochromators	106
3.4.1	The Lyot Filter	106
3.4.2	Tuning: the Universal Filter	110
3.4.3	A Tunable Michelson Interferometer	111
3.4.4	The Fabry–Perot Interferometer	112
3.4.5	A Magneto-Optical Filter	115
3.4.6	A Double Monochromator	116
3.4.7	The Spectroheliograph	117
3.5	Polarimetry	118
3.5.1	Zeeman Splitting	118
3.5.2	Polarized Light	121
3.5.3	Unno’s Equations	123
3.5.4	Solar Polarimeters	131
3.5.5	Scattering Polarization and Hanle Effect	136
3.6	Special-Purpose Instruments	137
3.6.1	The Pyrheliometer	137
3.6.2	Neutrino Detectors	139
3.6.3	The Coronagraph	143
3.7	Bibliographical Notes	145

4. The Atmosphere	149
4.1 Radiative Transfer – Local Thermodynamic Equilibrium	149
4.1.1 The Equation of Transfer	149
4.1.2 Various Equilibria	150
4.1.3 Absorption Lines in LTE	152
4.2 Radiative Transfer – Statistical Equilibrium	154
4.2.1 Model Assumptions	154
4.2.2 Line Radiation and Einstein Coefficients	155
4.2.3 Continuum Radiation	157
4.2.4 Collisions	158
4.2.5 The Source Function	158
4.2.6 The Equations of Statistical Equilibrium	161
4.3 Atmospheric Models	162
4.3.1 Limb Darkening	162
4.3.2 Model Calculations in LTE	164
4.3.3 Models with Departures from LTE	169
4.4 The Chemical Composition of the Sun	175
4.4.1 Spectrum Synthesis	175
4.4.2 The Light Elements Lithium, Beryllium, and Boron	176
4.4.3 Helium	178
4.5 Bibliographical Notes	179
5. Oscillations	181
5.1 Observations	181
5.1.1 Five-Minute Oscillations	181
5.1.2 The Spectrum of Solar Oscillations	184
5.1.3 Low-Degree p Modes	189
5.1.4 Line Width and Line Asymmetry	193
5.2 Linear Adiabatic Oscillations of a Non-Rotating Sun	194
5.2.1 Basic Equations	194
5.2.2 Spherical Harmonic Representation	195
5.2.3 The Cowling Approximation	197
5.2.4 Local Treatment	198
5.2.5 Boundary Conditions	205
5.2.6 Asymptotic Results	207
5.3 Helioseismology	211
5.3.1 Direct Modeling and Inversion	211
5.3.2 Speed of Sound in the Solar Interior	213
5.3.3 Depth of the Convection Zone	215
5.3.4 Chemical Constitution	217
5.3.5 Equation of State	218
5.3.6 Internal Mixing	219
5.3.7 Precise Determination of the Solar Radius	220
5.3.8 Internal Rotation	220
5.3.9 Travel Time and Acoustic Imaging	226

5.4	Excitation and Damping	229
5.4.1	The κ Mechanism	229
5.4.2	Stochastic Excitation by Convection	230
5.5	Bibliographical Notes	232
6.	Convection	237
6.1	Stability	237
6.2	Mixing-Length Theory	239
6.2.1	The Local Formalism	240
6.2.2	Numerical Test Calculations	243
6.2.3	Overshooting: A Non-local Formalism	245
6.3	Granulation	248
6.3.1	The Observed Pattern	248
6.3.2	Models	257
6.3.3	Mean Line Profiles	261
6.4	Mesogranulation	265
6.5	Supergranulation	267
6.5.1	The Velocity Field and the Network	267
6.5.2	Convective Nature	269
6.5.3	The Effect of Rotation	270
6.6	Giant Cells	271
6.6.1	Tracer Results	271
6.6.2	Spectroscopic Results	273
6.7	Bibliographical Notes	274
7.	Rotation	277
7.1	Axis of Rotation	277
7.2	Oblateness	279
7.2.1	Origin	279
7.2.2	Measurements	280
7.3	Rotational History	281
7.3.1	The Initial State	281
7.3.2	Torques	283
7.3.3	Evolution of the Solar Rotation	286
7.4	The Angular Velocity of the Sun	288
7.4.1	The Internal Angular Velocity	288
7.4.2	The Angular Velocity at the Surface	289
7.4.3	Meridional Circulation	295
7.4.4	Correlation of Flow Components	296
7.5	Models of a Rotating Convection Zone	297
7.5.1	Conservation of Angular Momentum	297
7.5.2	Mean-Field Models	298
7.5.3	Explicit Models	301
7.6	Bibliographical Notes	303

8. Magnetism	305
8.1 Fields and Conducting Matter	305
8.1.1 The Induction Equation	305
8.1.2 Electrical Conductivity on the Sun	307
8.1.3 Frozen Magnetic Field	309
8.1.4 The Magnetic Force	310
8.2 Flux Tubes	312
8.2.1 Concentration of Magnetic Flux	312
8.2.2 Observational Evidence for Flux Tubes	318
8.2.3 Vertical Thin Flux Tubes	327
8.2.4 Curved Thin Flux Tubes	333
8.2.5 Thermal Structure of Photospheric Tubes	340
8.3 Sunspots	342
8.3.1 Evolution and Classification	342
8.3.2 Sunspot Models	346
8.3.3 Sunspots and the “Solar Constant”	354
8.3.4 Dots and Grains	356
8.3.5 Oscillations in Sunspots	359
8.3.6 The Evershed Effect	361
8.4 The Solar Cycle	364
8.4.1 Global Magnetism	364
8.4.2 Mean-Field Electrodynamics	368
8.4.3 The Kinematic $\alpha\Omega$ Dynamo	372
8.4.4 The Magnetohydrodynamic Solar Dynamo	378
8.5 Bibliographical Notes	382
9. Chromosphere, Corona, and Solar Wind	387
9.1 Empirical Facts	387
9.1.1 The Chromosphere	387
9.1.2 The Transition Region	392
9.1.3 The Corona	394
9.1.4 The Wind	403
9.2 Consequences of High Temperature	409
9.2.1 Heat Conduction	409
9.2.2 Expansion	411
9.3 The Magnetic Field in the Outer Atmosphere	413
9.3.1 Magnetic Field Measurements	413
9.3.2 Potential Field Extrapolation	414
9.3.3 The Force-Free Field	417
9.3.4 Prominences	419
9.3.5 Magnetic Braking of Solar Rotation	422
9.4 The Energy Balance	425
9.4.1 Needs	425
9.4.2 Heating	427
9.5 Explosive Events	431

XVI Table of Contents

9.5.1	Flares and Other Eruptions	432
9.5.2	Release of Magnetic Energy	438
9.6	Bibliographical Notes	440
List of Symbols		443
References		453
Index		485



<http://www.springer.com/978-3-540-20741-2>

The Sun

An Introduction

Stix, M.

2002, XVI, 492 p., Hardcover

ISBN: 978-3-540-20741-2